

Thermal Instability of a Homogeneous Viscous Magnetized Rotating Plasma under the Effects of Finite Electron Inertia and Fine Dust particles

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ABSTRACT

In this paper we have investigated the problem of gravitational instability of gaseous plasma incorporating viscosity, thermal conductivity, rotation, finite electron inertia, magnetic field and in the presence of finite dust particles. With the help of linearized perturbed equations of the problem a general dispersion relation is obtained. The general dispersion relation is discussed in different way of our interest.

Keywords: Thermal Instability, Finite Electron Inertia, Suspended Particles, Rotation, Magnetic Field.

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1. INTRODUCTION

The gravitational instability of an infinite homogeneous self-gravitating interstellar medium was first discovered by Jeans¹. And latter a detailed contribution of

the Jeans instability with different assumption on the magnetic field and rotation has been discussed by Chandrasekhar². In this connection, many authors have investigated the Jeans instability of a homogeneous Plasma considering the

effects of various parameters. Chhajlani and Sanghvi³, Chhajlani and Vyas⁴, Prajapati *et al.*⁵, Bora and Talwar⁶, Pensia *et al.*⁷.

In their paper we examine the validity of Jeans criterion when an infinitely extending homogeneous gaseous medium is rotating uniformly in the presence of finite dust particles and transverse magnetic field incorporating the effects of thermal conductivity and finite electron inertia.

2. LINEARIZED PERTURBATION EQUATIONS

We consider an infinite homogeneous, viscous, Self-gravitating, rotating ionized plasma composed of gas and the fine dust particles (suspended particles) incorporating thermal conducting and finite electron inertia.

Linearized Perturbation Equations of the Problem are,

$$\frac{\delta \vec{v}}{\delta t} = -\frac{\vec{\nabla} \delta P}{\rho} + \vec{\nabla} \delta \phi + \frac{KN}{\rho} (\vec{u} - \vec{v}) + \vartheta \nabla^2 \vec{v} + \frac{1}{4\pi\rho} (\vec{\nabla} \times \vec{b}) \times \vec{B} + 2(\vec{v} \times \vec{\Omega}) \quad (1)$$

$$\frac{\partial \delta \rho}{\partial t} = -\rho \vec{\nabla} \cdot \vec{v} \quad (2)$$

$$\delta P = C^2 \delta \rho \quad (3)$$

$$\nabla^2 \delta \phi = -4\pi G \delta \rho \quad (4)$$

$$\left(\tau \frac{\partial}{\partial t} + 1 \right) \vec{u} = \vec{v} \quad (5)$$

$$\lambda \nabla^2 \delta T = \rho C_p \frac{\partial \delta T}{\partial t} - \frac{\partial \delta P}{\partial t} \quad (6)$$

$$\frac{\delta P}{P} = \frac{\delta T}{T} + \frac{\delta \rho}{\rho} \quad (7)$$

$$\frac{\partial \vec{b}}{\partial t} = (\vec{B} \cdot \vec{\nabla}) \vec{v} - (\vec{v} \cdot \vec{\nabla}) \vec{B} + \frac{c^2}{\omega_{pe}^2} \frac{\partial}{\partial t} \nabla^2 \vec{b} \quad (8)$$

Where,

$\vec{v}(v_x, v_y, v_z), \vec{u}(u_x, u_y, u_z), N, \rho, P, \phi, \vec{B}(0, 0, B), \vec{\Omega}(\Omega_x, 0, \Omega_z), T, G, \vartheta, C_p, \lambda, R, m, \rho_s, \omega_{pe}, K_s(6\pi\rho r)$ and $\vec{b}(b_x, b_y, b_z)$ denote respectively, the gas velocity, the particle velocity, the number density of the particle, density of the gas, pressure of the gas, Gravitational potential, magnetic field, rotation, temperature, Gravitational constant, kinematic viscosity, specific heat at constant pressure, thermal conductivity, gas constant, mass per unit volume of the particles its density, plasma frequency of electron, the constant is the stoken drag formula and the perturbation in magnetic field.

3. DISPERSION RELATION

We analyze these perturbations with normal oscillation technique; we find solution of equation (1)-(8). In a uniform system we can find a plane-wave solution with all variables varying as,

$$\exp\{i(k_x x, k_z z, \omega t)\} \quad (9)$$

Where k_x, k_z are the wave numbers of perturbation along the x and z-axis so that $k_x^2 + k_z^2 = k^2$ and the frequency of harmonic disturbances, Using (2)-(9) in (1), we obtain the following algebraic equations for the components

$$M_1 v_x - 2\Omega_z v_y + \frac{ik_x}{k^2} \Omega_T^2 s = 0 \quad (10)$$

$$2\Omega_z v_x + M_2 u_y - 2\Omega_z v_z = 0 \quad (11)$$

$$2\Omega_x u_y + d_1 v_z + \frac{ik_z}{k^2} \Omega_T^2 s = 0 \quad (12)$$

The divergence of (1) with the aid of (2)-(9) gives

$$\frac{ik_x v^2 k^2}{A_1} v_x + 2i(k_x \Omega_z - \Omega_x k_z) v_y - M_3 s = 0 \quad (13)$$

Where $s = \frac{\delta \rho}{\rho}$ is the condensation of the medium

$\gamma = \frac{c_p}{c_v} = \frac{c^2}{c'^2}$ ratio of the specific heat,

$V = \frac{B}{\sqrt{4\pi\rho}}$ is the Alfvén velocity,

$\Omega_s = \frac{KN}{\rho}$ has the dimension of

frequency, $\tau = \frac{m}{K_s}$ is the relaxation time,

$\beta = \tau \Omega_s = \frac{\rho s}{\rho}$ is the mass conservation,

$\sigma = i\omega$ is the growth rate of perturbation,

$\Omega_\theta = \theta K^2$, $A_1 = \sigma f$,

$f = \left(1 + \frac{c^2 K^2}{\omega_{pe}^2}\right)$, $\theta_k = \frac{\lambda}{\rho c_p}$

is the thermometric Conductivity,

C and C' is the adiabatic and isothermal velocities of sound.

$$d_1 = \sigma + \Omega_\theta + \frac{\beta \sigma}{\sigma \tau + 1} \Omega_j^2 = (C^2 K^2 - 4\pi G \rho)$$

$$\Omega_j^2 = (C'^2 K^2 - 4\pi G \rho) \Omega_r^2 = \frac{\sigma \Omega_j^2 + \gamma_k \Omega_j^2}{\sigma + \gamma_k}$$

$$M_1 = \left(d_1 + \frac{V^2 K^2}{A_1}\right),$$

$$M_2 = \left(d_1 + \frac{V^2 K_z^2}{A_1}\right),$$

$$M_3 = (\sigma d_1 + \Omega_r^2),$$

$$M_4 = (k_x \Omega_z - \Omega_x k_z)$$

The nontrivial solution of the determinant of the matrix obtained from (11)-(13) with

(v_x, v_y, v_z) having various coefficients, that should vanish is to give the following dispersion relation.

$$d_1 \left[\sigma d_1 \{M_1 M_2 + 4\Omega^2\} + \frac{4\Omega_x^2 V^2 K^2 \sigma}{A_1} + \Omega_r^2 \left\{ M_2^2 + 4\Omega^2 - \frac{4M_4^2}{K^2} \right\} \right] = 0 \quad (15)$$

The dispersion relation¹⁵ shows the combined influence of fine dust particles thermal conductivity, finite electron inertia, magnetic field, viscosity and rotation of the self-gravitational instability of a homogeneous plasma. If we ignore the effect of finite electron inertia then¹⁵ reduces to Chhajlani and Vyas⁴. The present results are also similar to those of Chhajlani and Sanghvi³ in the absence of rotation and finite electron inertia neglecting the contribution of finite Larmor radius (FLR) connection and Hall parameter in that case. In the absence of finite fine dust particles¹⁵ give similar result as are obtained by Prajapati *et al.*⁵ excluding the effects of arbitrary radiative heat-loss functions, permeability, electrical resistivity and Hall-effect in that case.

Thus with these correlations we find that the dispersion relation (15) is modified due to the combined effects of finite dust particles, finite electron inertia, rotation, magnetic field, viscosity and thermal conductivity. This dispersion relation will be able to predict the complete information about the a coustic wave, Alfvén wave and Jeans gravitational instability of the gaseous plasmas considered. The above dispersion relation is very lengthy and to analysis the effects of each parameter we now reduce the dispersion relation¹⁵ for two modes of propagation.

4. ANALYSIS OF THE DISPERSION RELATION

4.1. Longitudinal mode of propagation ($K \parallel B$)

For this case we assume that all the perturbations and longitudinal to the direction of the magnetic field

(i.e. $K_z = K$, $K_x = 0$).

Thus the dispersion relation (15) reduces in the simple form to give

$$\sigma d_1 \left\{ \left(d_1 + \frac{K^2 V^2}{A_1} \right)^2 + 4\Omega^2 \right\} + \frac{4\sigma V^2 K^2}{A_1} \Omega_x^2 + \Omega_T^2 \left\{ \left(d_1 + \frac{K^2 V^2}{A_1} \right)^2 + 4\Omega_z^2 \right\} = 0 \quad (16)$$

This dispersion relation is further reduced for rotational axes are parallel and perpendicular to the direction of the magnetic field for simplicity.

4.1.1. Axis of rotation parallel to the magnetic field ($\Omega \parallel B$).

When the axis of rotation is along the magnetic field, i.e. $\Omega_x = 0$ and $\Omega_z = \Omega$. Then (16) reduces to as

$$\left(\sigma d_1 + \Omega_T^2 \right) \left[\left(\sigma + \Omega_\theta + \frac{\beta\sigma}{\sigma\tau+1} + \frac{K^2 V^2}{A_1} \right)^2 + 4\Omega^2 \right] = 0 \quad (17)$$

This dispersion relation shows the combined influence of fine dust particles, finite electron inertia, viscosity, rotation, magnetic field and thermal conductivity on the self-gravitational instability of the hydro-magnetic fluid plasma. In the absence of fine dust particles, finite electron inertia,

permeability, rotation and radiative heat-loss function. This dispersion relation reduces to that Chhajlani and Patidar⁵. The dispersion relation¹⁷ is the product of relation¹⁷ is the product of two independent factors. These factors show mode of propagations incorporating different parameters as discussed below.

The first factor of¹⁷ is identical to that of Chhajlani and Vyas with porosity = 1 in that case and has been discussed by them. This represents a stable damped mode modified due to the viscosity, finite dust particles and thermal conductivity. The dynamical stability of the system can be examined by applying the Hurwitz criterion on the mode of propagation represented by first factor of the dispersion relation¹⁷.

It can also be seen that, for the longitudinal propagation in the medium, Jeans condition remains unaltered even by the inclusion of the effect of fine dust particles and finite electron inertia. Owing to the inclusion of thermal conductivity the isothermal sound velocity is replaced by the adiabatic velocity of sound. The second factor of¹⁷ gives, on substituting the value of d_1 , A_1 the following Six degree polynomial equation.

$$\begin{aligned} & \tau^2 f^2 \sigma^6 + 2\tau \sigma^5 f^2 [1 + \tau(\beta + \Omega_\theta)] \\ & + \sigma^4 [f^2 \{1 + \tau(\beta + \Omega_\theta)\}^2 \\ & + 2\tau(\Omega_\theta f + \tau K^2 V^2) + 4\tau^2 f^2 \Omega^2] \\ & + \sigma^3 [2\tau f K^2 V^2 + 8\tau f^2 \Omega^2 \\ & + 2f(f\Omega_\theta + \tau K^2 V^2)\{1 + \tau(\beta + \Omega_\theta)\}] \\ & + \sigma^2 [(f\Omega_\theta + \tau K^2 V^2)^2 \\ & + 2f K^2 V^2 \{1 + \tau(\beta + \Omega_\theta)\} + 4f^2 \Omega^2] \\ & + \sigma [2K^2 V^2 (f\Omega_\theta + \tau K^2 V^2)] + K^4 V^4 \\ & = 0 \end{aligned} \quad (18)$$

The dispersion relation (18) is a non-gravitating Alfven mode modified by the presence of fine dust particles, finite electron inertia, viscosity and rotation. We find that in this dispersion relation the terms due to the finite electron inertia have entered through the factor of.

4.1.2. Axis of rotation perpendicular to the magnetic field($\Omega \perp B$).

In the case of a rotation axis perpendicular to the magnetic field, we put $\Omega_x = \Omega$ and $\Omega_z = 0$ in the dispersion relation (16) and this gives,

$$(d_1 A_1 + K^2 V^2) [(d_1 A_1 + K^2 V^2) (\sigma d_1 + \Omega_T^2) + 4\sigma A_1 \Omega^2] = 0 \quad (19)$$

This dispersion relation is the product of two independent factors. These factors show the mode of propagations incorporating different parameters as discussed below.

The first factor of¹⁹ also represents a stable non-gravitating Alfven mode modified by fine dust particles, finite electron inertia and viscosity but this mode is not affected by rotation.

Thus we see that Alfven mode is not affected by rotation in longitudinal mode of propagation when axis of rotation is taken perpendicular to the direction of magnetic field while this non-gravitating Alfven mode is affected by rotations when axis of rotation is taken to parallel to the magnetic field. The second factor (19) gives on substituting the values of d_1, A_1 and Ω_T^2 , the following seven degree polynomial equation.

$$\begin{aligned} & \tau^2 \sigma^7 f + \sigma^6 [\tau f \{2 + \tau(2\Omega_\theta + 2\beta + \theta_k)\}] \\ & + \sigma^5 [f \{1 + 2\tau(2\Omega_\theta + \beta + \theta_k)\}] \\ & + \tau^2 \{f \Omega_j^2 + K^2 V^2 + 4f \Omega^2 + f(\beta + \Omega_\theta)(\Omega_\theta + \beta + 2\theta_k)\} \\ & + \sigma^4 [f(2\Omega_\theta + \theta_k) + 2\tau \{f \Omega_j^2 + K^2 V^2 + 4f \Omega^2 + f(\beta + \Omega_\theta)(\Omega_\theta + \theta_k) + f \Omega_\theta \theta_k\}] \\ & + \tau^2 \{\theta_k(f \Omega_j^2 + K^2 V^2 + 4f \Omega^2) + (\beta + \Omega_\theta)(f \Omega_j^2 + K^2 V^2 + f \beta \theta_k + f \Omega_\theta \theta_k)\} \\ & + \sigma^3 [(f \Omega_j^2 + K^2 V^2 + 4f \Omega^2 + f \Omega_\theta^2 + 2f \Omega_\theta \theta_k) \\ & + \tau \{(\beta + \Omega_\theta)(f \Omega_j^2 + K^2 V^2 + 2f \Omega_\theta \theta_k) + \Omega_\theta(f \Omega_j^2 + K^2 V^2) \\ & + 2\theta_k(f \Omega_j^2 + K^2 V^2 + 4f \Omega^2)\} + \tau^2 \{K^2 V^2 \Omega_j^2 + \theta_k(\beta + \Omega_\theta)(f \Omega_j^2 + K^2 V^2)\}] \\ & + \sigma^2 [\Omega_\theta(f \Omega_j^2 + K^2 V^2 + f \Omega_\theta \theta_k) + \theta_k(f \Omega_j^2 + K^2 V^2 + 4f \Omega^2) \\ & + \tau \{2K^2 V^2 \Omega_j^2 + 2\Omega_\theta \theta_k(f \Omega_j^2 + K^2 V^2)\} + \tau^2 K^2 V^2 \theta_k \Omega_j^2 + \tau \beta \theta_k(f \Omega_j^2 + K^2 V^2)] \\ & + \sigma [K^2 V^2 \Omega_j^2 + \Omega_\theta \theta_k(f \Omega_j^2 + K^2 V^2) + 2\tau K^2 V^2 \theta_k \Omega_j^2] + K^2 V^2 \theta_k \Omega_j^2 = 0 \end{aligned} \quad (20)$$

These dispersion relation as presents the effect of the simultaneous inclusion of the fine dust particles, finite electron inertia, thermal conductivity, viscosity, rotation and magnetic field on the

self-gravitational instability of the system for longitudinal propagation with the axis of rotation perpendicular to the magnetic field. The condition of instability and the expression of the critical Jeans wave are

obtained from the constant term of²⁰, which is identical to that of obtained by Chhajlani and Vyas⁸.

We find that is the dispersion relation²⁰ some terms are multiplied by terms due to the finite electron inertia, but the constant terms is independent of the finite electron inertia.

Hence the condition of instability well not be affected by the presence of finite electron inertia, but the growth rate of the system well be changed. It is also find that the condition of instability well not changed by the viscosity and the presence of fine dust particles.

4.2. TRANSVERSE MODE OF PROPAGATION($K \perp B$):

For this case we assume all the perturbations transverse to the direction of the magnetic field(*i.e.* $K_x = K$, $K_z = 0$). Thus the dispersion relation (15) becomes

$$\sigma \left[d_1 \{ M_1 d_1 + 4\Omega^2 \} + \frac{4\Omega_x^2 V^2 K^2}{A_1} \right] + \Omega_T^2 (d_1^2 + 4\Omega_x^2) = 0 \quad (21)$$

The dispersion relation²¹ shows the influence of finite electron inertia, presence of finite dust particles, rotation, viscosity, magnetic field and thermal conductivity on the self-gravitational of infinite homogeneous plasma. In the absence of finite electron inertia²¹ reduces to that of Chhajlani and Vyas⁴ with taking porosity $\varepsilon = 1$ and neglecting permeability in that case. If we ignore finite electron inertia and rotation²¹ is similar to those of Chhajlani and Sangvi³ in the absence of FLR corrections and Hall effect is that case. The presents results are also similar to those of Prajapati *et al.*⁵ in the

absence of arbitrary radiative heat-loss functions permeability, electrical resistivity and Hall effect in that case.

Now we discuss this dispersion relation²¹ is the case of rotation axes parallel and perpendicular to the magnetic field.

4.2.1. Axis of rotation parallel to the magnetic field ($\Omega \parallel B$).

When the axis of rotation is along the magnetic field, we put

$\Omega_x = 0$ and $\Omega_z = \Omega$ and then the dispersion relation²¹ be comes,

$$d_1 [d_1 \{ \sigma M_1 + \Omega_T^2 \} + 4\sigma \Omega^2] = 0 \quad (22)$$

This dispersion relation shows the combined influence of finite electron inertia, viscosity, rotation, presence of finite dust particles, and thermal conductivity on the self-gravitational instability of the hydro-magnetic fluid plasma.

In the absence of finite electron inertia, rotation and finite dust particles this dispersion relation reduces to that of Chhajlani and Parihar⁹ with ignoring the effect of Hall current, electrical resistivity and permeability of that case. In the absence of finite electron inertia and finite dust particles this dispersion relation is identical to that obtained by Vyas and Chhajlani⁸ with neglecting the contribution of finite dust particles, Hall current, electrical resistivity and permeability in that case. In the absence of fine dust particles, finite electron inertia, rotation²¹ give similar results as are obtained by Chhajlani and Parihar⁹ excluding the effects of Hall current, electrical resistivity, permeability and porosity in that case. The dispersion relation²² has two independent

factors, each representing different modes of propagations.

relation is stable mode as discussed in the previous case and the second factor of the dispersion relations²² simplification written as

The first factor of this dispersion

$$\begin{aligned} & \tau^2 \sigma^6 + \sigma^5 \tau [2\{1 + \tau(\beta + \vartheta_k)\} + \tau\theta_k] \\ & + \sigma^4 \left[\tau^2 \left(\Omega_j^2 + \frac{k^2 V^2 \sigma}{A_1} + 4\Omega^2 \right) + 2\tau\vartheta_k \right. \\ & + \{1 + \tau(\beta + \vartheta_k)\} \{1 + \tau(\beta + \vartheta_k + 2\theta_k)\} \Big] \\ & + \sigma^3 \left[\tau^2 \theta_k \left(\Omega_j^2 + \frac{k^2 V^2 \sigma}{A_1} + 4\Omega^2 \right) + \tau \left(\Omega_j^2 + \frac{k^2 V^2 \sigma}{A_1} + 8\Omega^2 + 2\vartheta_k \theta_k \right) \right. \\ & + \{1 + \tau(\beta + \vartheta_k)\} \left\{ (2\vartheta_k + \theta_k) + \tau \left(\Omega_j^2 + \frac{k^2 V^2 \sigma}{A_1} + \vartheta_k \theta_k + \beta \theta_k \right) \right\} \Big] \\ & + \sigma^2 \left[(\vartheta_k^2 + 4\Omega^2) \right. \\ & + \{1 + \tau(\beta + \vartheta_k)\} \left\{ \Omega_j^2 + \frac{k^2 V^2 \sigma}{A_1} + 2\vartheta_k \theta_k + \tau\theta_k (\Omega_j^2 + k^2 V^2) \right\} \\ & + \tau \left\{ \vartheta_k \left(\Omega_j^2 + \frac{k^2 V^2 \sigma}{A_1} \right) + \theta_k \left(\Omega_j^2 + \frac{k^2 V^2 \sigma}{A_1} + 8\Omega^2 \right) \right\} \Big] \\ & + \sigma \left[\vartheta_k \left(\Omega_j^2 + \frac{k^2 V^2 \sigma}{A_1} + \vartheta_k \theta_k \right) + \tau\theta_k \left(\Omega_j^2 + \frac{k^2 V^2 \sigma}{A_1} \right) \right. \\ & + \theta_k \{1 + \tau(\beta + \vartheta_k)\} \left(\Omega_j^2 + \frac{k^2 V^2 \sigma}{A_1} \right) \Big] + \vartheta_k \theta_k \left(\Omega_j^2 + \frac{k^2 V^2 \sigma}{A_1} \right) = 0 \quad (23) \end{aligned}$$

This is Six degree polynomial equations and shows the combined influence of fine dust particles, viscosity, rotations, magnetic field, thermal conductivity and heat-loss functions in the transverse mode of propagation when axis of rotation is parallel to the direction of magnetic field.

4.2.2. Axis of rotation perpendicular to the magnetic field ($\Omega \perp B$):-

In the case of a rotation axis perpendicular to the magnetic field i.e. $\Omega_x = \Omega$ and $\Omega_z = 0$

Then we get following dispersion relation.

$$(d_1^2 + 4\Omega^2) \{ \sigma M_1 + \Omega_T^2 \} = 0 \quad (24)$$

The first factor of (24) gives as

$$\begin{aligned} & \sigma^4 \tau^2 + \sigma^3 2\tau \{1 + \tau(\beta + \vartheta_k)\} \\ & + \sigma^2 \left[\{1 + \tau(\beta + \vartheta_k)\}^2 + 2\tau\vartheta_k + \tau^2 4\Omega^2 \right] \\ & + 2\sigma \left[\vartheta_k \{1 + \tau(\beta + \vartheta_k)\} + \tau 4\Omega^2 \right] + \vartheta_k^2 \\ & + 4\Omega^2 = 0 \quad (25) \end{aligned}$$

This is four degree polynomial equation and show the combined influence of various parameters.

The second factor of dispersion relation (24) simplification written as.

$$\sigma^4\tau + \sigma^3\{1 + \tau(\beta + \vartheta_k + \theta_k)\} + \sigma^2\left[\vartheta_k + \theta_k + \tau\left(\Omega_j^2 + \frac{k^2V^2\sigma}{A_1} + \beta\theta_k + \theta_k\vartheta_k\right)\right] + \sigma\left[\left(\Omega_j^2 + \frac{k^2V^2\sigma}{A_1} + \vartheta_k\theta_k\right) + \tau\theta_k\left(\Omega_j^2 + \frac{k^2V^2\sigma}{A_1}\right)\right] + \theta_k\left(\Omega_j^2 + \frac{k^2V^2\sigma}{A_1}\right) = 0 \quad (26)$$

This is four degree polynomial equation and show the combined influence of various parameters, fine dust particles, viscosity, rotations, magnetic field, thermal conductivity and heat-loss functions in the transverse mode of propagation when axis of rotation perpendicular to the magnetic field.

5. CONCLUSIONS

In the present paper, we have investigated the problem of Jeans instability of a finite homogeneous, self-gravitating magnetized rotating gaseous plasma under the influence of finite electron inertia and effect of fine dust particles. We find that our results are modified due to the combined effect of fine dust particles, Thermal conductivity, viscosity, finite electron inertia, magnetic field as compared to previous results obtained by various authors.

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